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ABSTRACT

The result of insufficient niacin consumption, pellagra caused more deaths than any other nutrition-related disease in American history, and it reached epidemic proportions in the South during the early 1900s. In this paper, we explore the forces that drove the rise and fall of pellagra. Historical observers have long-believed that pellagra stemmed from the South's monoculture in cotton, which displaced the local production of nutritionally-rich foods. To test this hypothesis, we begin by showing that, at the county level, pellagra rates are positively correlated with cotton production. We then exploit the arrival of the boll weevil—which prompted Southern farmers to begin planting food instead of cotton—to show that this correlation is likely causal. We close by studying how fortification laws passed during the 1940s helped to eliminate pellagra.

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1. Introduction

Although largely unheard of in the United States today, no other nutrition-related disease in American history has caused as many deaths as pellagra. The by-product of insufficient niacin consumption, pellagra reached epidemic proportions in the American South during the first half of the twentieth century, killing nearly 7,000 Southerners annually at its peak in 1928 (Bollet 1992).[1] Pellagra largely disappeared from the South during the mid-twentieth century. In this paper, we explore the forces that drove the rise and fall of pellagra in the South, and in the process, we contribute to literatures in both economic history and economic development. As explained further below, our results are particularly relevant to three areas: the first is a long-standing claim that cash cropping and monocultures adversely affect nutrition, and in extreme cases, leave societies vulnerable to famines (e.g., Mokyr 1983, O'grada 1995)[2]; the second is an older but still vibrant literature exploring the sources of delayed economic growth and development in the American South (e.g., Alston and Ferrie 1993, Wright 1987, Wright 2013); and the third is the literature that explores nutritional shocks (e.g. Lumey et al. 2011).

We begin our analysis by exploring a standard, but largely untested, explanation for the rise of pellagra in the American South: widespread cotton production is thought to have displaced local production of niacin-rich foods and driven poor Southern farmers and mill workers to consume milled Midwestern corn, which was relatively cheap but also devoid of the niacin necessary to prevent pellagra (Park et al. 2000, Goldberger et al. 1920, Rajakumar 2000). Exploiting newly digitized cause of death data at the county-level for North Carolina and South Carolina, we find that places with high cotton acreage also had high pellagra death rates. Our estimates suggest that if the South did not produce any cotton the pellagra death rate would have decreased by 14%. Additionally, if Southern farmers changed their land use from cotton production to corn production the pellagra death rate would have decreased by about 48%.

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[1] The *Mortality Statistics of the United States* report 6,824 deaths from pellagra in the year 1928. Assuming a case fatality rate of 3 percent (Goldberger et al. 1928), this suggests there were approximately 230,000 cases of pellagra in the United States in 1928, which is equivalent to the population of Atlanta at the time. In places where pellagra was endemic, Goldberger et al. (1928) estimated that around 20 percent of all households had at least one person sick with the disease, though other sources (e.g., Love and Davenport 1920) suggest lower incidence rates. While pellagra was not as pervasive as hookworm (which infected around one-third of the Southern population) pellagra is an extreme indicator: one need not have developed a full-blown case of pellagra to have been poorly nourished, and according to some observers (e.g., Etheridge 1972, Youmans 1964), the high incidence of pellagra is suggestive of broader nutritional deficits.

[2] For an argument that cash cropping led to famines in India see Bhatia (1963).

A central concern with these estimates is that they might conflate changes in income with changes in food availability: perhaps years of high cotton production were also years of low income, and it was the reduction in income, not the reduction in local food production, that drove the increase in pellagra. Such concerns are only heightened by the contentious but long-standing claim that cotton over-production left farmers much poorer than they otherwise would have been (Decanio 1973).[3] To disentangle these effects, we exploit the arrival of the boll weevil in the cotton belt during the early 1900s. The boll weevil reduced both contemporaneous income and cotton production, and yet, we find, that its arrival was associated with increased food production and reduced pellagra rates. To demonstrate that the reduced pellagra rates are from improved nutrition, and not an overall trend of improved health, we run placebo tests and show that the boll weevil did not impact other, non-nutrition, diseases.

Having explored cotton's role in the rise of pellagra, we then turn to an analysis of the forces that broke the correlation between cotton production and pellagra, and helped bring an end to the disease in the American South. Pellagra rates dropped sharply, and permanently, during the 1930s and 1940s. Because this drop happens at around the same time as the passage of state and federal laws encouraging and mandating that breads and grains be enriched with niacin, historical observers have long hypothesized a causal connection between the laws and the reduction in pellagra, but that hypothesis has not been formally tested. Using a panel of state-level data and a standard difference-in-differences set-up, we exploit the interstate variation in the timing of niacin-fortification laws to identify their effects on pellagra and other nutrition-related diseases. The results suggest fortification laws significantly reduced pellagra related mortality.

Taken together, our results contribute to three literatures. First, the observation that malnutrition can emerge in poor agricultural societies that rely heavily on cash crops is not unique to the American South; development economists and colonial historians offer similar arguments for other parts of the world (e.g. National Academy of Sciences 1978, p. 44; and Bhatia 1963). Second, the American South has long lagged behind the North in economic performance, and only after World War II did incomes begin to converge. Standard explanations

[3] Also see the debate between Wright and Kunreuther (1975), Mcguire and Higgs (1977), Wright and Kunreuther (1977), and Mcguire (1980) on the riskiness of cotton production.

for these patterns fall into one of three categories: institutional, technological, and disease-related.[4] The results here suggest a fourth possible mechanism: improved nutrition.

Third, most literature that explores nutritional shocks achieves identification by focusing on shocks that adversely affect both nutrition and income (see Lumey et al. 2011 for a literature review). The results here complement and extend this literature. Of particular interest is our use of the boll weevil, which breaks the usual correlation between nutrition and income. Most shocks that reduce nutrition also reduce income, and it is difficult to disentangle the two effects as they are mutually reinforcing. The boll weevil, however, forced farmers to abandon a profitable crop (cotton) for less profitable crops (local food) and yet, because the shift to less profitable crops was often associated with expansions in local food supplies, there are sound theoretical reasons to believe these shocks resulted in improved nutrition despite any reductions in income. The data bear out this hypothesis.

2. Historical background and preliminary observations

Historically, physicians and public health experts have characterized pellagra by the four D's: dermatitis, diarrhea, dementia, and death. Other symptoms include: sensitivity to sunlight; aggression; emotional disturbances; edema; inflammation of the tongue; skin lesions; insomnia; weakness; mental confusion; ataxia (loss of coordination) and paralysis in the extremities; and enlarged heart. Much like smallpox, which gave rise to a distinctive rash unique to the disease, the dermatitis and skin discoloration associated with severe cases of pellagra facilitated a proper diagnosis. That said, for less severe cases, where the pathognomonic features of the disease were less pronounced pellagra would have been harder to distinguish from other ailments and may well have been underreported. These observations have clear implications for our empirical analysis. In short, death rates for pellagra are probably well estimated because of the distinctiveness of the disease in severe cases, but incidence rates likely understate the prevalence of the disease.

Today the causes of pellagra are well understood. As noted above, the primary cause of the disease is inadequate niacin consumption, and secondary causes include a deficiency in

[4] Institutional explanations consider national labor standards (Wright 1987); Civil Rights legislation (Wright 2013, Collins 2003); and the decline of paternalism and other institutions hostile to black economic progress (Alston and Ferrie 1993, 1999). Technological explanations focus on air-conditioning (Biddle 2008, 2011), electrification (Downs 2014), and the mechanization of agriculture (Alston and Ferrie 1993, 1999). Disease-based explanations consider the eradication of hookworm and malaria (Bleakley 2007, 2010; Kitchens 2013).

tryptophan (which is found in meat, fish, and eggs, and the body converts into niacin) and excess leucine (which inhibits niacin metabolism). Historically, however, the causes of pellagra were poorly understood. During the early 1900s, Southerners steadfastly rejected any claim that the disease might be associated with poverty and poor diets. They saw such claims as an indictment of Southern culture and habits, and instead argued that pellagra was spread by flies or spoiled corn (Mooney et al. 2014, Siler et al. 1914, 1915). The first person to effectively argue that pellagra was a nutritional disease was Joseph Goldberger, who worked for the United States Public Health Service in the late 1910s and early 1920s. Through a series of detailed studies of diets in orphanages, sanitariums, and mill towns, Goldberger and his colleagues documented a tight correlation between diet and pellagra (Goldberger et al. 1915, 1920, 1929). However, it was not until 1937 that Conrad Elvehjem showed definitively that pellagra was caused by inadequate niacin consumption (Elvehjem et al. 1937).

The first reported case of pellagra in the United States occurred in Georgia in 1902 and reached broader proliferation around 1906 (Bollet 1992). Historical observers have attributed the emergence of pellagra to changes in the milling of Midwestern corn. Previous milling technology had removed less of the germ, retaining some niacin. Newer technology removed the germ more completely, leading to a finer cornmeal with a longer shelf life, but much less niacin and other micronutrients. Expansion of large-scale milling and movements of goods by railroad meant that this corn reached the South in increasing quantities. Bollet (1992, p. 219) notes that “in the textile mill towns, surrounded by cotton fields, food was shipped in by railroad, and the cornmeal that could be purchased in the company stores was processed in the Midwest, where it had been degerminated.” In addition, a survey conducted by the Thompson-McFadden Pellagra Commission of residents in six mill towns in South Carolina revealed that almost 60% of residents consumed shipped cornmeal on a daily basis and only 10% of residents never consumed shipped cornmeal. In contrast, locally produced cornmeal was consumed by only 12% of residents on a daily basis, while 80% of residents never consumed locally produced cornmeal. The complete results from the survey are shown in Table 1 (Siler et al. 1915).

Figure 1 maps the regional variation in pellagra rates and shows that this change in corn milling and the subsequent emergence of pellagra hit the South particularly hard. While there was some pellagra in the border states and the Southwest, the disease reached its peak in the deep

South, particularly, Alabama, the Carolinas, Florida, Georgia, Louisiana, Mississippi, and Tennessee.

Why did the change in corn milling hit the South so hard? Aside from salt pork and molasses (neither of which was particularly high in niacin), the Southern diet was based mostly on corn. Niacin rich foods, such as fish, lamb, and poultry, were expensive and were not regularly consumed by poor Southern households (Hilliard 1969). Table 2 documents the Southern proclivity to eat corn. This table is based on The Study of Consumer Purchases in the United States, 1935-1936, which collected data on food purchases from a large sample of households including Southern households in both urban and rural areas. The table reports significant differences in the average amounts of cornmeal, hominy grits, and white bread consumed by Southern households compared to non-Southern households. While rural households in the South ate less white bread than non-Southerners, they consumed far more cornmeal and hominy grits (which are made from corn; column (3)). In particular, Southern rural households consumed 4.25 pounds of cornmeal and hominy and 1.13 pounds of white bread per week. Non-Southern households consumed 0.09 pounds of cornmeal and hominy and 4.33 pounds of white bread per week. These differences are all highly significant. Column (2) shows that Southern urban households also relied heavily on cornmeal and hominy grits, although there consumption of white bread was similar to non-Southern households.

The introduction of degerminated Midwestern corn probably would not have mattered as much had Southerners produced more corn for local consumption. Corn that was grown and marketed for local consumption would have been consumed relatively quickly and the incentives to preserve it through milling and degermination would have been relatively small. Locally sourced corn could also be used to make hominy grits. If prepared correctly (in a lime/alkali solution), hominy grits contained more niacin than ordinary corn, cornmeal, or corn bread. In addition, Southerners tended to plant and harvest sweet corn, which contained relatively high levels of niacin, while the corn varieties grown in the Midwest contained 30 to 50 percent less niacin than sweet corn (Burkholder et al. 1944; Ayer 1895, p. 12-13). The upshot of all this is that as long as Southerners were consuming fresh, locally-grown corn that was not milled they would have been consuming more niacin than they did with imported Midwestern corn.

One of the central themes of the extent literature on pellagra is that the disease stemmed directly from the South's cotton monoculture. In his study of South Carolina, Walter Edgar

(1992) argues that a high debt burden forced many farmers to plant cotton, a cash crop with higher expected returns than other crops such as foods for the local market. In 1910, one of every five cultivated acres was devoted to cotton; by 1919 one of every two cultivated acres was devoted to cotton. Furthermore, despite the population of South Carolina tripling from 1850 to 1935, the amount of food production remained about the same. As a result, South Carolina "had to import $70-$100 million worth of food annually. For poverty-stricken tenant farmers with little ready cash, this meant that there was less to eat. The consequent increased dependence on a diet of pork, cornbread, and molasses made poor Carolinians more susceptible to disease" (Edgar 1992, pg. 47).

A more general way to state this argument is the following: the production of cotton displaced local food production, and prompted poor Southern cotton farmers and laborers to import and consume corn from the Midwest, which though cheap, was also degerminated and devoid of niacin. If so, one would expect a strong positive correlation with cotton production and pellagra. In years when cotton production was high (and crowded-out the harvesting of food for local markets) pellagra rates should have risen, while in years of low cotton production (and by implication, relatively high rates of local food production) pellagra rates should have fallen. Formal econometric evidence, to be presented later, supports this notion, but we begin by presenting graphical evidence of the relationship between pellagra and cotton.

Panel A of Figure 2 plots two time-series: the pellagra death rate in the American South from 1910 to 1950 and cotton-acres harvested from 1880 to 1950. These data suggest that pellagra erupted in the American South after two decades of steady growth in the amount of Southern farmland dedicated to cotton production. The explosive growth in pellagra stops during the late 1910s at around the same time that the cotton economy stagnates with the penetration of the boll weevil. Pellagra rebounds during the late 1920s, shortly after the effects of the boll weevil begin to recede and the cotton economy recovers. Pellagra plummets again during the late 1920s and early 1930s, with the onset of the Great Depression and a sharp decline in cotton-acres harvested. It is only after the discovery of niacin in 1937, marked by the dashed-horizontal line in the graph, and the passage of laws mandating the fortification of grains and breads with niacin, that the correlation between cotton production and pellagra seems to break down. Panels B, C, and D of Figure 2 plot similar graphs for North Carolina, South Carolina, and Louisiana. Because North Carolina and South Carolina are the only states that report pellagra deaths at the county level during this time period, they will prove particularly important in our empirical analysis.

Plotting the pellagra death rate directly against annual cotton acres harvested, Figure 3 highlights the correlation between pellagra and cotton production more clearly. What remains unclear, however, is the extent to which one might attribute causality to this relationship. One obvious concern is the large number of potentially confounding events during the 1900-1950 period. In particular, there is a well-developed literature documenting the long-term economic significance of the events like the Great Influenza Pandemic (Almond 2006, Clay et al. 2015, and Noymer 2010); iron enrichment (Niemesh 2015); the Great Migration (Black et al. 2015); various New Deal programs, particularly those aimed at agriculture (Depew et al. 2013) the eradication of malaria and hookworm (Bleakley 2007, 2010); milk fortification; and salt iodization (Adhvaryu et al. 2015, Feyrer et al. 2013). Any of these events might confound the time series above and/or interact with pellagra in important ways.

We believe that the influence of these confounders will have limited impact on our empirical analysis and we take several steps to control for these and other potential confounders. We believe that many of the confounders will be differenced out with year and state/county fixed effects (e.g. the Great Influenza Pandemic was unique to 1918 and 1919). We will also control for the malaria death rate.[5] Finally, for interventions like milk fortification, migration, and salt iodization to drive our results they would have to work through very specific channels. For instance, for migration to be driving our results it must be the case that people sick with pellagra migrate out of an area, but other unhealthy individuals (e.g., those sick with typhoid or tuberculosis) do not. Similar stories would need to be told for milk fortification and salt iodization, whereby adding vitamin D to milk and iodine to salt somehow leads people to consume more niacin.

Building on an older literature, one might also argue that the South was over-producing cotton, and that as a result, years of high cotton production were also years of low income.[6] In this case, pellagra would not have been the result of cotton displacing local food production (and raising the price of such food). Instead, the disease would have stemmed from the fact that cotton

[5] Hookworm infection rates are not available for many counties in South Carolina (see Thoman 2009) so we do not control for the hookworm infection rate in our main analyses since it would dramatically reduce our sample size. Results controlling for the hookworm infection rate are available upon request.

[6] See Mcguire and Higgs (1977) and Mcguire (1980) for evidence on the profitability of cotton.

production was driving down income and the reduction in income, not the displacement of local food, caused families in the cotton South to consume less food. As explained in the introduction, and further below, we exploit the arrival of the boll weevil to address this possibility.

3. A simple economic framework

In this section, we sketch out a simple economic framework that can explain how the South's reliance on cotton might have promoted higher pellagra rates in particular, and poor nutrition more generally construed. One of the central messages of this framework is that cash cropping does not necessarily result in poor nutrition; it only does so under certain conditions.

Consider, then, a largely agricultural economy, where farmers are deciding how to allocate their land, labor, and capital: they can either plant, harvest, and sell a cash crop in an international market (in this case, cotton); or they can deploy their resources to produce food for the local market. In deciding how to allocate resources, farmers look toward expected prices.[7] To the extent expected cotton prices are relatively high, farmers would allocate their land and resources to planting and selling cotton and produce little food for the local market. This would decrease the supply of locally produced foods, driving up the relative price. Consumers in this economy would then substitute away from local foods and begin importing degerminated corn from the Midwest, which as noted above, was niacin deficient. As an empirical matter, we cannot observe the expected price of cotton or the price of locally produced foods. However, we can observe acres dedicated to cotton and food production, which is perhaps an even better indicator of farmers' beliefs about the expected relative profitability of food and cotton. In addition, we will also discuss and exploit situations were expected prices do not drive planting decisions, such as the arrival of the boll weevil, which left farmers no choice but to shift away from cotton.

For the process above to have yielded high rates of pellagra, two conditions need to be satisfied. First, it must be the case that there are, in fact, nutritional differences between imported corn and locally-sourced foods. While we cannot directly test this proposition, there is anecdotal evidence to suggest this was the case. In the case of corn, locally-produced corn did not require degermination to extend shelf life and so it is thought to have been healthier and richer in niacin.

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[7] Risk might also enter such considerations but in the case of the American South, cotton not only exhibited higher average profitability; it also had lower variance and was a relatively low risk crop. See McGuire and Higgs (1977) and McGuire (1980).

There is also evidence (discussed below) that aside from corn, Southern farmers would switch to growing peanuts and sweet potatoes when cotton prices were low or when cotton production was not feasible. Peanuts and sweet potatoes are both rich in niacin and other micronutrients. Second, it must be the case that the price effect dominates any income effect. More precisely, if demand for nutrition grows with income and higher cotton prices, it is possible that consumers in the region might begin importing relatively expensive niacin-rich foods, rather than degerminated corn. Having said this, nutritionally rich foods in general, and foods that were high in niacin, in particular, were poorly understood during our study period. Put another way, if cash cropping generates sufficiently high wages and income, and nutrition is a normal good, cash cropping need not imply poor nutrition.

4. Data

4.a. Dependent variables

To document the relationship between cotton and the rise and fall of pellagra in the American South our main dependent variable is the pellagra death rate, which we collect at both the county and state levels. Consistent reporting of pellagra deaths at the county level during our study period (circa 1900-1950) are, to our knowledge, only available for North Carolina and South Carolina. Pellagra deaths for counties in North Carolina from 1915-1949 come from *The Annual Report of the Bureau of Vital Statistics of the North Carolina State Board of Health*.[8] The North Carolina State Board of Health did not issue a Vital Statistics report for the years 1918 and 1919; accordingly we do not have data on deaths for these years. Pellagra deaths for counties in South Carolina from 1915-1949 come from *Annual Report of the State Board of Health of South Carolina*. We also collected county-level deaths in North Carolina from 1915-1925 for the following diseases: malaria, measles, pneumonia, typhoid, and tuberculosis.[9] We use these diseases as placebo tests in our analysis.

Because our county analysis is limited to North Carolina and South Carolina we also collect pellagra deaths at the state level for Southern states: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina,

[8] In 1920 and 1921 these reports are found in *The Health Bulletin* published by the North Carolina State Board of Health.

[9] Ideally, we would have collected these data for South Carolina as well, but the death rates for these diseases are missing for much of our study period. Typhoid fever deaths are not consistently reported in South Carolina until 1919; pneumonia and measles deaths are not consistently reported until 1934.

Tennessee, and Virginia. Texas did not report state level pellagra deaths until 1933 and is, therefore, excluded from our analyses. These data are taken from the *Mortality Statistics of the United States* (1900-1936) and the *Vital Statistics of the United States* (1937-1949). To calculate yearly pellagra death rates at the county and state levels we perform a linear interpolation of the county and state populations in-between decennial censuses.

4.b. Independent variables

Our first independent variable of interest is cotton acreage per capita at the county-level, which come from Haines et al. (2015) *United States Agriculture Data, 1840-2010*. These data are digitized versions of data originally provided in publications from the United States Bureau of the Census and provide county-level crop production for years in which the Census of Agriculture was performed (1909, 1919, 1924, and 1929 are the ones used in this paper). Beyond cotton acreage per capita, we also use data on corn, peanut, sweet potato, and tobacco acreage per capita.

Our second independent variable of interest is an indicator variable that takes a value of one after the boll weevil arrived in a county. Data on the year the boll weevil first arrived in a county are taken from Lange et al. (2009), which originally came from USDA boll weevil maps. Finally, we use an indicator variable that takes a value of one after a state passed a fortification law. The year of state fortification law passage was taken from Park et al. (2001) and is shown in Figure 1.

5. Cotton and the rise of pellagra

5.a. Relationship between cotton and pellagra

Although the existing literature on pellagra posits a causal relationship between cotton production and pellagra, there is a dearth of systematic data establishing even a correlation between the two. Accordingly, in this section, we use county-level data to formally explore the relationship between cotton production, local food production, and pellagra. To do this we estimate the following model:

$$ln[pellagra]_{ct} = \alpha + \theta * ln[cotton\ acres\ pc]_{ct} + \theta_t + \varepsilon_{ct} \qquad (1)$$

In equation (1), $ln[pellagra]_{ct}$ is the log of the pellagra death rate in county c in year t, where county c is a county in North Carolina or South Carolina. The variable $ln[cotton\ acres\ pc]_{ct}$ is the log of cotton acres per capita. θ_t are year fixed effects to control for any unobserved shocks in a particular year that might effect the pellagra death rate. We estimate equation (1) on the years 1919, 1924, and 1929 since the relationship between cotton acres per capita and pellagra might change during the Great Depression and after the discovery of niacin in 1937. Finally, we restrict to counties that had at least 100 acres of farmland devoted to cotton production in 1889. These restrictions give us 103 counties during three census years, for a total of 309 observations. Standard errors are clustered at the county level.

The results from estimating equation (1) are given in Table 3. In column (1), an increase in cotton acres per capita by 10% increases the pellagra death rate by 1.4% [p-value = 0.19]. Columns (2)-(4) show that when counties use their land to produce local food, instead of cotton, the pellagra death rate is significantly lower. For instance, in column (2) a 10% increase in corn acres per capita reduces the pellagra death rate by 4.5%. Finally column (5) includes all crop variables and shows that cotton acres per capita continues to have a positive and significant effect on the pellagra death rate, while corn and peanut acres per capita continue to have a negative and significant effect on the pellagra death rate. We use the estimates in column (5) to predict what would happen to the pellagra death rate if the South did not produce any cotton. Predicting the pellagra death rate in the South with cotton acres per capita set to zero for every county would have resulted in a decrease in the pellagra death rate by 14% (the pellagra death rate would have decreased from 0.88 log points to 0.76 log points). This calculation is assuming that the land used for cotton production is left in fallow. If we, instead, assign that land to be used to produce corn the pellagra death rate would have decreased by 48% (from 0.88 log points to 0.46 log points).[10]

Table 3 provides evidence consistent with the historical narrative that one of the primary causes of the rise of pellagra in the United States was the South's cotton monoculture and lack of crop diversity. In the pre-niacin fortification period, the pellagra death rate increased when land devoted to cotton production increased, and decreased when the land devoted to local food production increased. Since land is fixed, if farmers decide to dedicate more land to cotton production they, necessarily, must dedicate less land to the production of locally grown food.

[10] This is found by predicting the pellagra death rate with cotton acres per capita set to zero and corn acres per capita set to the average number of acres devoted to cotton + corn production in the counties, which is 1.26 log acres per capita.

The decline in local food production resulted in individuals consuming more imported food, which had lower nutritional value.

Despite the results in Table 3 there is still the potential concern that high cotton production is associated with unobserved factors that increase the pellagra death rate. For example, perhaps high cotton production actually decreases income (Decanio 1973), which leads to worse diets and increases in pellagra. To deal with these concerns, we next turn our attention to the arrival of the boll weevil. While the boll weevil reduced the incomes of Southern famers, the evidence below suggests it also prompted those farmers to switch from cotton to food production. Pellagra rates fell as a result, but rebounded after the boll weevil receded.

5.b. The boll weevil

The boll weevil, a beetle that feeds on cotton leaves, squares (flower buds), and bolls, appeared in Texas in 1892. Figure 4 shows its progression through the cotton belt. By 1922, the boll weevil had infected the entire cotton region. The arrival of the weevil had significant impacts on agriculture. Lange et al. (2009) show that the arrival of the boll weevil reduced county cotton production, yields, and land values. They also find evidence that farmers shifted crops after the arrival of the boll weevil (p. 710): "The decline in cotton acreage raises the question of what southern farmers did with the released land…Overall, the corn results indicate a greater movement to alternative crops than suggested in the literature, which has downplayed the boll weevil's effects on diversification." They also write in a footnote that (p. 710): "Based on the census data, we also find production of hay, Irish potatoes, peanuts, rice, and sweet potatoes; sugar cane, among other crops, showed statistically significant increases after the arrival of the weevil."

The invasion of the boll weevil allows us to exploit an exogenous change in crop mix that arguably affected health. We first examine the effects of the boll weevil on crop diversification in North Carolina and South Carolina using a specification similar to Lange et al. (2009):

$$ln[crop\ acreage\ pc]_{ct} = \alpha + \theta_1 * [boll\ weevil]_{ct} \times [intensity]_c + \theta_2 * tS_c + \theta_3 * t^2 S_c + \theta_c + \theta_t + \varepsilon_{ct} \quad (2)$$

In equation (2), $ln[crop\ acreage\ pc]_{ct}$ is the log of per capita acres dedicated to cotton, corn, peanuts, sweet potatoes, or tobacco. $[boll\ weevil]_{ct}$ is an indicator variable that takes a value of one after the boll weevil has arrived in a county.[11] We interact this variable with a county level measure of the intensity of the treatment: $[intensity]_c$. Our intensity measure is an indicator variable if county c was in the top 25% of the distribution of cotton acres per capita in North and South Carolina in 1909. We include a quadratic time trend, t and t^2, interacted with the share of cotton in total acres harvested in 1889, S_c. Finally, we include county fixed effects to control for unobserved time invariant county characteristics and year fixed effects to control for any unobserved shocks in a particular year that might affect crop acreage. We, again, restrict to counties that had at least 100 acres of farmland devoted to cotton production in 1889. This leaves us with 102 counties during four census years (1909, 1919, 1924 and 1929) for a total of 408 observations. Standard errors are clustered at the county level.

Table 4 displays the results from estimating equation (2). In column (1) the dependent variable is the log of cotton acres per capita. The first row, (1), displays the coefficient on the post boll weevil indicator. The second row, (2), displays the coefficient on the interacted variable. Finally, row (3) displays the sum of the coefficients in columns (1) and (2) and is interpreted as the effect of the boll weevil in high cotton acreage counties. In column (1), the coefficient in row (3) indicates that cotton acreage per capita in North Carolina and South Carolina increased insignificantly by less than 2% after the arrival of the boll weevil. The coefficient in row (3) of column (2) indicates that cotton yields fell by approximately 7% after the arrival of the boll weevil. North Carolina and South Carolina were among the last Southern states to be invaded by the boll weevil and the insignificant change in cotton acreage coupled with the fall in cotton yield are consistent with farmers switching to earlier maturing, lower yielding varieties of cotton, which was one of the few mitigation methods available to combat the beetle.[12] Columns (3), (4), and (5) suggest that the arrival of the boll weevil in North Carolina and South Carolina was also associated with a diversification of crops and an expansion in acreage per capita dedicated to food crops. High cotton acreage counties saw an 8% increase in corn acres per capita, a 3% increase in peanut acres per capita, and a 1.2% increase in sweet potato acres per capita after the arrival of the boll weevil. Finally, column (6) suggests that high cotton acreage counties saw an insignificant decrease in per capita tobacco acres by 1.9% after the boll weevil. The results in

[11] The boll weevil arrived in South Carolina from 1917-1921 and it arrived in North Carolina from 1919-1922.

[12] We replicate the findings of Lange et al. (2009) when using the entire South. These findings suggest that cotton acreage per capita significantly decreases after the arrival of the boll weevil. These regressions for the entire South are available upon request.

Table 4 confirm the results from Lange et al. (2009). Namely, cotton yields decreased after the arrival of the boll weevil and acres per capita devoted to food production significantly increased.

Next, we examine the impact the boll weevil had on pellagra through crop diversification. We motivate our analysis by showing the trends in the pellagra death rate for poorly nourished counties (above median pellagra rates prior to the boll weevil) and better nourished counties (below median pellagra rates prior to the boll weevil). Figure 5 Panel A displays the pellagra death rate for counties in South Carolina that were invaded by the boll weevil in the year 1919 (31 of the 46 counties in South Carolina were invaded in the year 1919; the most of any year in which South Carolina was invaded by the boll weevil). The blue line graphs the pellagra death rate for counties with above median pellagra rates, while the red line graphs the pellagra death rate for counties with below median pellagra rates. From the graph it appears that the pellagra death rates between the two groups of counties begin to converge after the arrival of the boll weevil, suggestive of relative improvements in nutrition in the high pellagra counties. Figure 5 Panel B displays an analogous graph for North Carolina counties that were invaded by the boll weevil in the year 1922 (35 of the 77 counties in North Carolina that were invaded by the boll weevil were invaded in the year 1922; the most of any year in which North Carolina was invaded by the boll weevil). Once again, the pellagra death rates between the two groups begin to converge after the arrival of the boll weevil.

To study the relationship between the boll weevil and pellagra formally we estimate the following equation:

$$\begin{aligned} ln[pellagra]_{ct} &= \alpha + \theta_1 * [boll\ weevil]_{ct} + \theta_2 * [boll\ weevil]_{ct} \\ &\times [intensity]_c + \theta_3 * tM_{c,1915} + \theta_4 * tU_{c,1910} + \theta_c + \theta_t + \varepsilon_{ct} \end{aligned} \quad (3)$$

In equation (3), $ln[pellagra]_{ct}$ is the log of the pellagra death rate in county *c* in year *t*. The rest of equation (3) is similar to equation (2), but we no longer control for the quadratic time trend. Instead we control for a linear time trend in the malaria death rate in 1915 and the urbanization rate in 1910. We use two different variables to measure intensity of treatment. Our first intensity of treatment variable is the average pellagra death rate in 1915 and 1916, just before the boll weevil arrived in North Carolina and South Carolina. The rationale for this intensity measure is that places with higher pre-boll weevil pellagra death rates likely had worse baseline nutrition and, therefore, had more to gain from the arrival of the boll weevil. This variable is normalized to have a mean of zero and a standard deviation of one. Our second intensity of treatment variable is the same as the variable used in Table 4: an indicator if county *c* was in the top 25% of the distribution of cotton acres per capita in North and South Carolina in 1909. Standard errors are clustered at the county-level. Since the boll weevil invaded North and South Carolina from 1917-1922, we use the sample period 1915-1925 (or 1915-1929). We have pellagra death data for 98 counties in North Carolina and 43 counties in South Carolina over this time period, giving us a sample of 141 counties and 1353 observations.[13]

As mentioned in Section 2 there are a number of factors that might confound our analysis. We believe that most of these factors will be differenced out as a result of our difference-in-differences approach. For example, if the Great Influenza Pandemic of 1918 interacts with pellagra, than this should only be true in the year 1918 and will be differenced out in our year fixed effects. According to Bleakley (2010) the malaria intervention in the American South occurs almost concurrently with the arrival of the boll weevil in North and South Carolina. Again, the malaria intervention might interact with pellagra and confound our results. Accordingly, we control for a linear time trend interacted with the county-level malaria death rate in 1915, just prior to the arrival of the boll weevil ($tM_{c,1915}$). We also control for a linear time trend interacted with the percent of the county population living in an urban area during the 1910 census ($tU_{c,1910}$). Finally, a valid potential confounder would involve migration out of counties that were hit by the boll weevil. We discuss this type of selection after we conduct our placebo tests below.

Table 5 shows the impact the boll weevil had on pellagra death rates in North and South Carolina. Columns (1)-(3) use the treatment period 1915-1925. The coefficient on the post boll weevil variable in column (1) indicates that the pellagra death rate decreased by 27% after the arrival of the boll weevil in a county. Column (2) indicates that for counties with the average amount of pellagra prior to the arrival of the boll weevil, the pellagra death rate decreased by 25% (the coefficient on Post boll weevil in column (2)). A one standard deviation increase in the pre-boll weevil pellagra death rate is associated with a decrease in the pellagra death rate of

[13] Recall that we do not have data on pellagra deaths in North Carolina for 1918 and 1919 (see Section 4), resulting in 882 observations for North Carolina (98 counties in 9 years). Additionally, we are missing data for Calhoun County and Laurens County South Carolina in the year 1915 meaning that we have 471 observations for South Carolina (43 counties in 11 years).

approximately 18%. The coefficients in column (3) show that pellagra decreased by 19% after the arrival of the boll weevil in a county, and pellagra decreased by an additional 27% in counties that had high pre-boll weevil cotton acreage per capita. Columns (4)-(6) repeat the analysis of columns (1)-(3), but use an extended treatment period, 1915-1929. The results using this extended treatment period remain similar.

In Table 6 we explore the robustness of these results by showing the effect of the boll weevil on diseases that are not caused by nutritional deficiencies.[14] We, again, estimate equation (3), but we only have county-level data on other diseases for the state of North Carolina as explained in Section 4.a. All columns of Table 6 control for a time trend interacted with the county-level malaria death rate in 1915 and a time trend interacted with the percent of the county population living in an urban area during the 1910 census. Column (1) displays the baseline effect of the boll weevil on pellagra in North Carolina. The arrival of the boll weevil is associated with a 19% decrease in the pellagra death rate. Columns (2)-(5) examine the effect of the arrival of the boll weevil on typhoid fever, tuberculosis, measles, and pneumonia, respectively. The boll weevil is not associated with significant decreases in the death rate of any of these non-nutrition related diseases. These placebo tests demonstrate that the arrival of the boll weevil was only associated with nutritional improvements and not short-run improvements in overall health.

As mentioned above, a potentially valid confounder of our boll weevil analysis involves migration out of counties that were hit by the boll weevil. Indeed, Lange et al. (2009, p. 715) find "the weevil appears to have unleashed a wave of internal migration, leading to local population gains before contact and substantial losses after the onset of significant crop damage." The placebo tests in Table 6 show that the least healthy members of the population are not selectively leaving a county after the arrival of the boll weevil. Therefore, for selective migration to be driving our results it must be the case that only individuals who are sick with pellagra migrate out of the county after the arrival of the boll weevil, while other unhealthy individuals stay put.

6. Niacin and the fall of pellagra

6.a. Voluntary fortification

[14] It is possible that improved nutrition might improve immunity leading to long-run gains in overall health. However, we believe that the short-run effects of improved nutrition would be most evident in nutritional diseases, like pellagra, not non-nutritional diseases.

Shortly after September 1937, when niacin was identified as the cause of pellagra, voluntary fortification of cereal-grain products began (Park et al. 2000, 2001). In 1939, the Council on Foods and Nutrition of the American Medical Association encouraged "with some qualification, fortification of certain staple foods with vitamins and minerals, specifically the restorative additions of thiamine, niacin, riboflavin, iron, and calcium to white flour and white bread" (Wilder 1956, pg. 1540). In 1941 the FDA established standards for the fortification of bread, which are displayed in Table 7. Up to January of 1943, fortification was increasingly common, but remained voluntary. Further, it was primarily restricted to bread and flour. Fortification was briefly required at the national level, due to War Food Order No. 1. When federal war powers ended, regulation devolved to the states, at which point, several states passed mandatory fortification laws.

Once again, we begin with a graphical analysis of the effect that voluntary fortification had on pellagra. Figure 6 displays an event-study, where we estimate equation (3), but replace the treatment indicator with a series of indicators that turn on for each year in the five years preceding and following 1938.[15] Of note is the fact that the pellagra death rate prior to voluntary fortification is consistently about 10% higher than it was in 1938. Following the introduction of voluntary fortification the pellagra death rate decreases every year. By 1940 the pellagra death rate was about 20% lower than it had been prior to fortification; by 1943 it was about 35% lower.

To analyze the effect that voluntary fortification had on pellagra formally we estimate equation (3), but $[boll\, weevil]_{ct}$ is replaced with a dummy variable that takes a value of one starting in 1938. We run this regression on county-level pellagra data for North and South Carolina and state-level pellagra data for Southern states as defined in Section 4.a. We again use two intensity of treatment variables. The first is the pellagra death rate in 1928, prior to the discovery of niacin (when pellagra was at its peak). This variable is standardized to have a mean of zero and a standard deviation of one. The second intensity of treatment variable is an indicator variable if county c was in the top 25% of the distribution of cotton acres per capita in North and South Carolina in 1909. When performing the state level analysis the second intensity of treatment variable is the state-level cotton acres per capita in 1909. We chose to use the continuous measure of cotton intensity for the state-level analysis, however, it makes little

[15] The indicator for the fifth year before 1938 includes all years 1925-1933 and the indicator for the fifth year after 1938 includes 1943-1949.

difference if we use an indicator variable instead of the continuous variable. The state-level cotton intensity measure is standardized to have a mean of zero and a standard deviation of one.

Table 8 provides the estimates from the specification described above. Columns (1)-(3) examine the county-level impact of voluntary fortification in North and South Carolina. In column (1), a one standard deviation increase in the pre-niacin pellagra death rate is associated with a decrease in the pellagra death rate by 24%. In column (2), counties with high cotton acreage per capita saw a decrease in the pellagra death rate by 24% after voluntary fortification. Column (3) identifies both intensity of treatment terms: a one standard deviation increase in the pre-niacin pellagra death rate is associated with a decrease in the pellagra death rate by 23% and counties with high cotton acreage per capita see a decrease in the pellagra death rate by 10% after voluntary fortification.

Columns (4)-(6) examine the state-level impact of voluntary fortification. Southern states, on average, experienced a 5% decrease in pellagra mortality after voluntary fortification began (column (4)). The coefficient on the intensity variable in column (5) is negative, but small in magnitude, indicating a decrease in the pellagra death rate of 1% after voluntary fortification. Column (6) identifies both intensity of treatment measures. The coefficient on the pellagra intensity measure is large and negative, while the coefficient on the cotton intensity measure is positive, but small in magnitude. The results in columns (4)-(6) indicate that states with poor baseline nutrition, as measured by the pellagra death rate, gain the most from voluntary fortification, whereas having a lot of cotton acres per capita is not predicative of improvements in nutrition.

6.b. Mandatory fortification laws

As shown in Figure 2, pellagra rates plummeted during the 1940s, and by the 1950s, the disease was largely eliminated from the United States. In this section, we explore the role that mandatory fortification laws played in the elimination of pellagra. Twenty-eight states passed some type of mandatory fortification law over the decade 1940-1949. Figure 1 shows the states and years in which fortification laws were passed. Most of these laws required bread and flour to be enriched with thiamine, niacin, riboflavin, iron, and calcium, however, many laws in Southern states also pertained to cornmeal and hominy grits.[16] As a result, major producers of cornmeal and grits in the Midwest began fortifying their products. A 1957 survey found that nearly all hominy grits sold were enriched, and that cornmeal was generally enriched, except in Florida and Virginia, where enrichment was less typical (Park et al. 2001, National Research Council 1958).

We again, estimate equation (3), but $[boll\ weevil]_{ct}$ is replaced with a dummy variable that takes a value of one starting in the year a state enacted a mandatory fortification law. Intensity of treatment variables are they same as in Section 6.a. Table 9 displays the results from the previously described specification. Columns (1)-(4) examine the county-level impacts of the North and Carolina fortification laws, which were passed in 1945 and 1942, respectively. In column (1), the passage of a fortification law is associated with an 18% decrease in the pellagra death rate. In column (2), a one standard deviation increase in the pre-niacin pellagra death rate is associated with an additional 19% decrease in the pellagra death. In column (3), counties with high cotton acreage saw an additional decrease in the pellagra death rate by 24% after mandatory fortification. Column (4) identifies both intensity of treatment coefficients, and the results remain similar. Columns (5)-(8) examine the state-level impacts of mandatory fortification laws. In column (5), the passage of a law is associated with a 3% decrease in the pellagra death rate. This decrease is almost entirely concentrated in states with high pre-niacin pellagra death rates as is shown in column (6). Column (7) and (8) again find little support for differential treatment based on the pre-niacin cotton acres per capita. Table 9 demonstrates that the passage of mandatory fortification laws were associated with significant decreases in the pellagra death rate. The passage of these laws were also associated with the virtual elimination of pellagra in the American South by 1950 as shown in Figure 2.

8. Conclusion

In this paper we have documented the rise and fall of pellagra in the United States. The rise of pellagra was associated with increases in cotton production in the American South and the substitution of locally grown corn for corn that was milled in the Midwest. The Midwestern milled corn was degerminated, which stripped the corn of much of its nutritional value. We show

[16] States that passed laws pertaining to cornmeal and hominy grits were: Alabama, Georgia, Mississippi, North Carolina, South Carolina, and Texas.

econometric evidence that pellagra is positively associated with the amount of land devoted to cotton production.

To establish the causal relationship between cotton acreage and pellagra we exploit an exogenous shock in cotton production that occurred from the arrival of the boll weevil. Farmers diversified crops after the arrival of the boll weevil, which led to improved nutrition and reductions in the pellagra death rate. Furthermore, we provide evidence that the arrival of the boll weevil was not associated with overall improvements in health. The death rates for typhoid, tuberculosis, measles, and pneumonia experienced no significant changes after the arrival of the boll weevil. This implies that the boll weevil's only short-run impact on health was through improved nutrition.

The fall of pellagra in the American South was the result of the discovery of niacin as an anti-pellagrant in 1937. Shortly after this discovery, bakeries and mills began to voluntarily fortify their products with thiamine, niacin, riboflavin, iron, and calcium. Pellagra was virtually eliminated in the United States with the passage of state-level mandatory cereal-grain fortification laws from 1940-1949. We show that both voluntary and mandatory fortification significantly decreased the pellagra death rate and led to pellagra's elimination around 1950.

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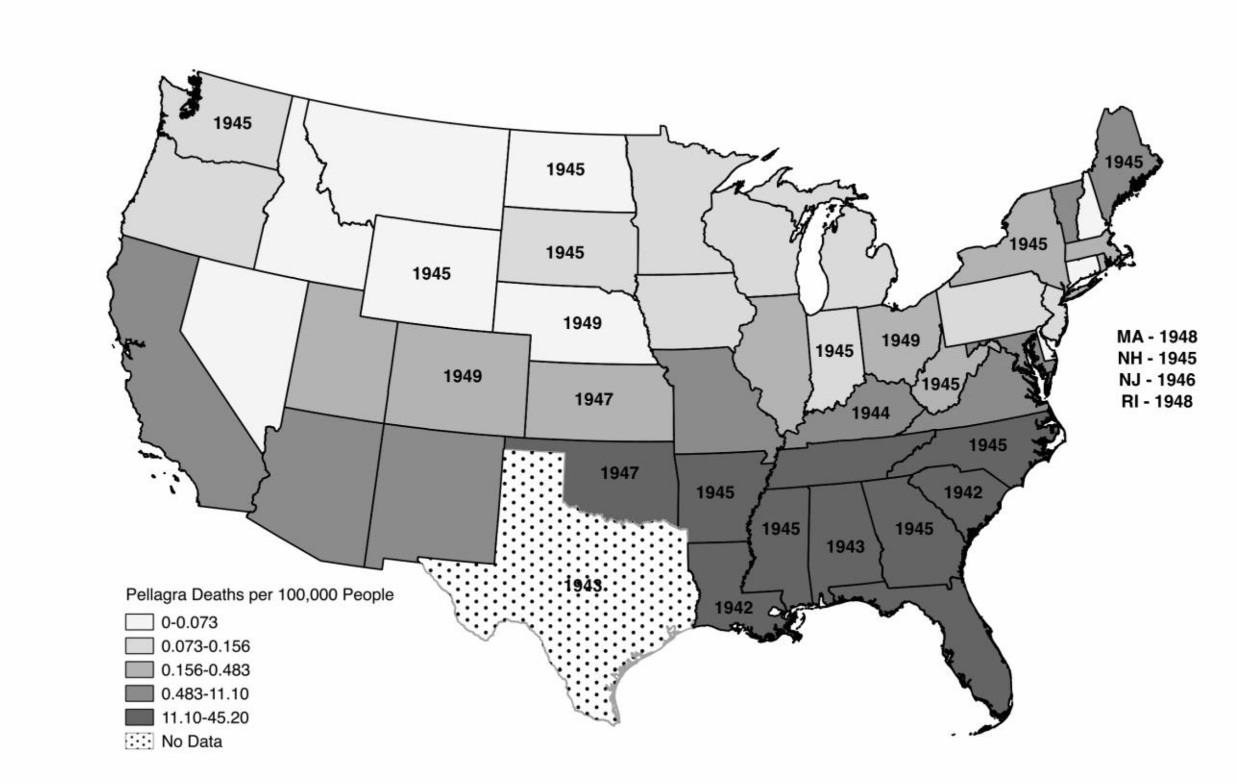
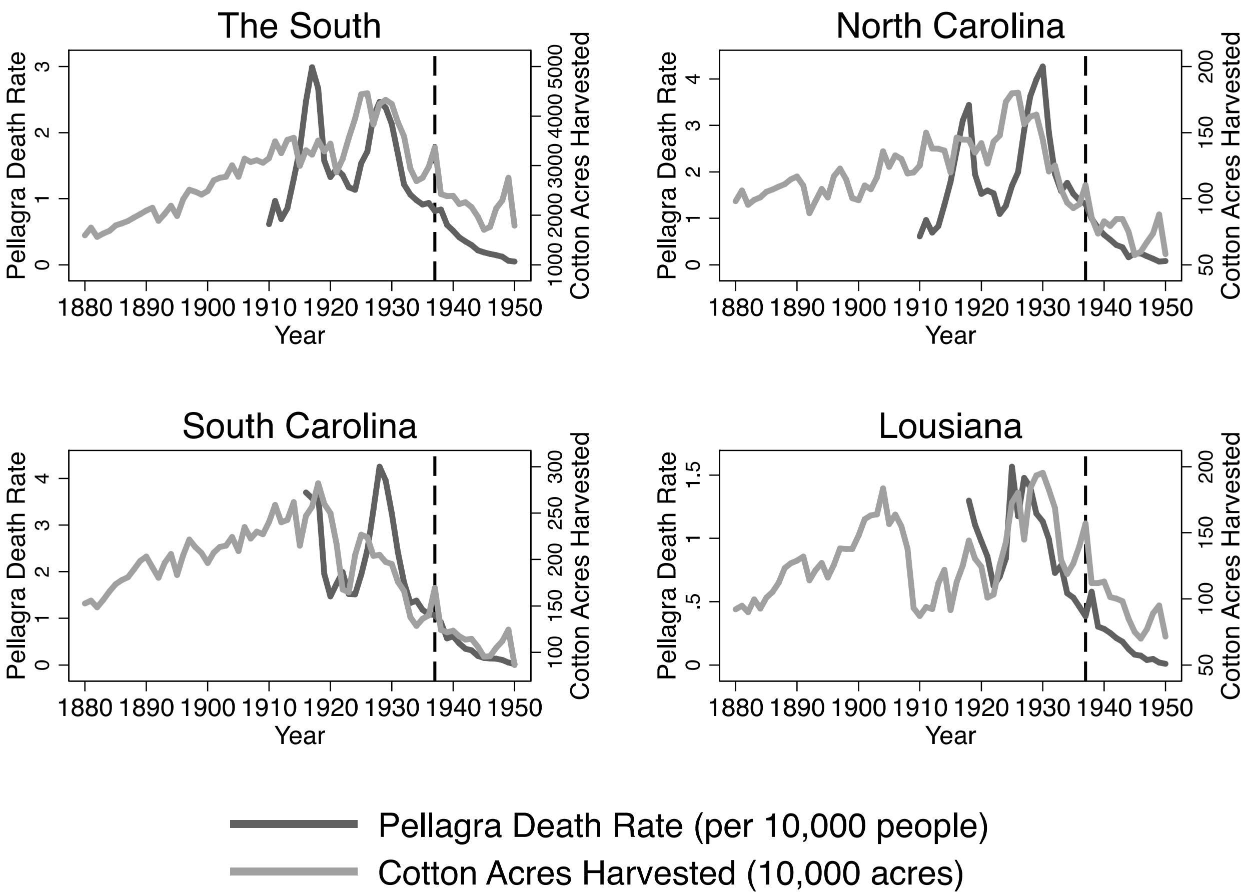
Figure 1: Distribution of pellagra (1930) and year of fortification law passage



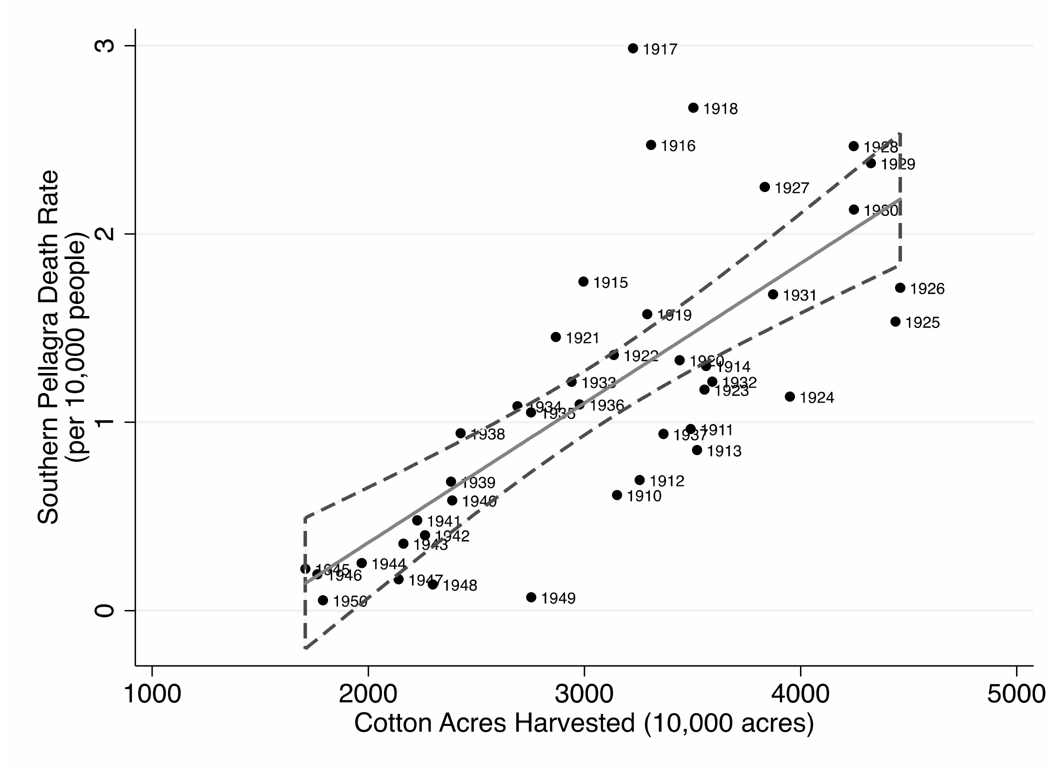
Notes: Pellagra deaths at the state-level for the year 1930 come from the *Mortality Statistics of the United States, 1930*.

Figure 2: Pellagra and cotton acreage in the South and three southern states



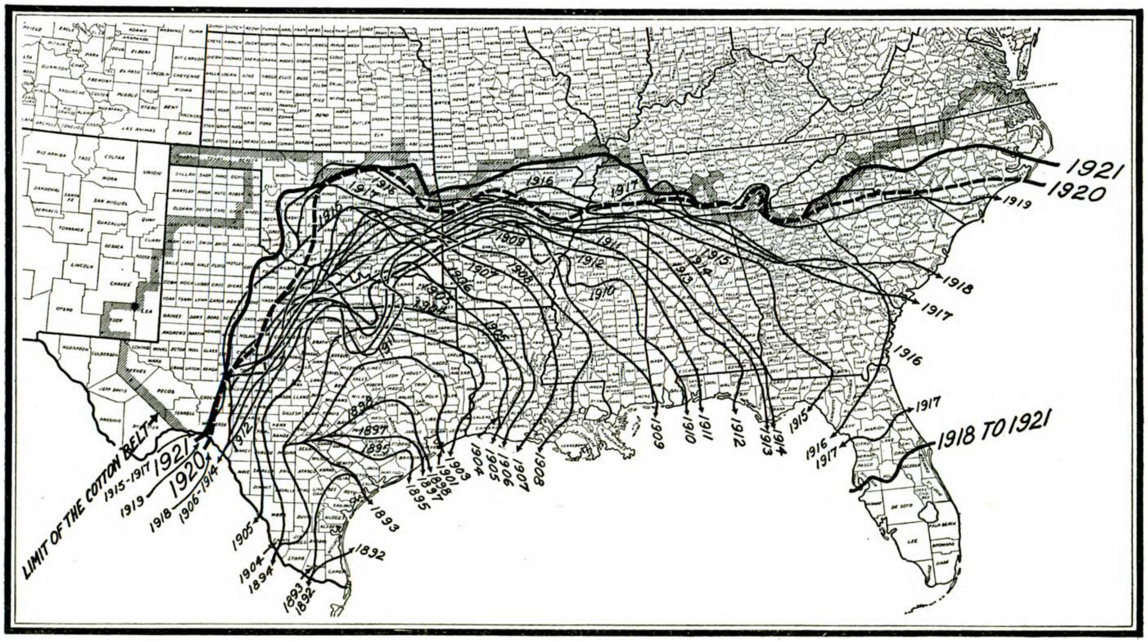
Notes: Pellagra deaths come from the *Mortality Statistics of the United States, 1900-1936* and the *Vital Statistics of the United States, 1937-1950*. The South is defined as (year pellagra deaths are first reported to the Mortality Statistics in parentheses): Alabama (1925), Arkansas (1927), Florida (1919), Georgia (1922), Louisiana (1918), Mississippi (1919), North Carolina (1910), Oklahoma (1928), South Carolina (1916), Tennessee (1917), and Virginia (1913). Cotton acres harvested were taken from the United States Department of Agriculture's National Agricultural Statistics Service Database (Quick Stats 2.0).

Figure 3: Relationship between cotton acres and pellagra in the American South



Notes: Pellagra deaths come from the *Mortality Statistics of the United States, 1900-1936* and the *Vital Statistics of the United States, 1937-1950*. The South is defined as: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas and Virginia. The fitted line and corresponding 95% confidence interval is the result of a linear regression through the plotted points.

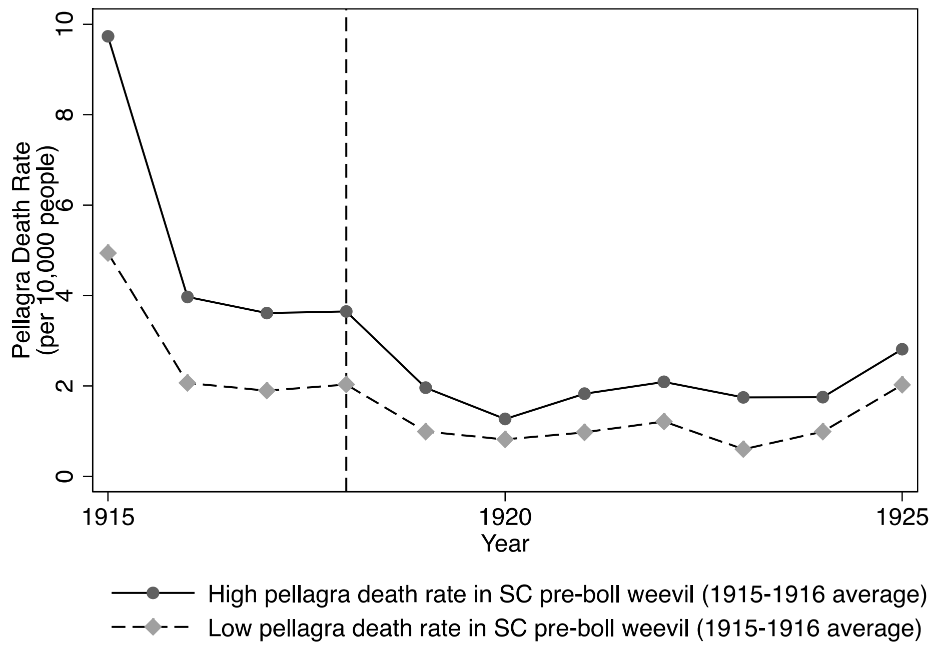
Figure 4: The progression of the boll weevil



Source: Hunter and Coad (1923) *The Boll weevil Problem.*

Figure 5: Pellagra and the Boll Weevil

Panel A: Counties in South Carolina that were invaded by the boll weevil in 1919



Panel B: Counties in North Carolina that were invaded by the boll weevil in 1922

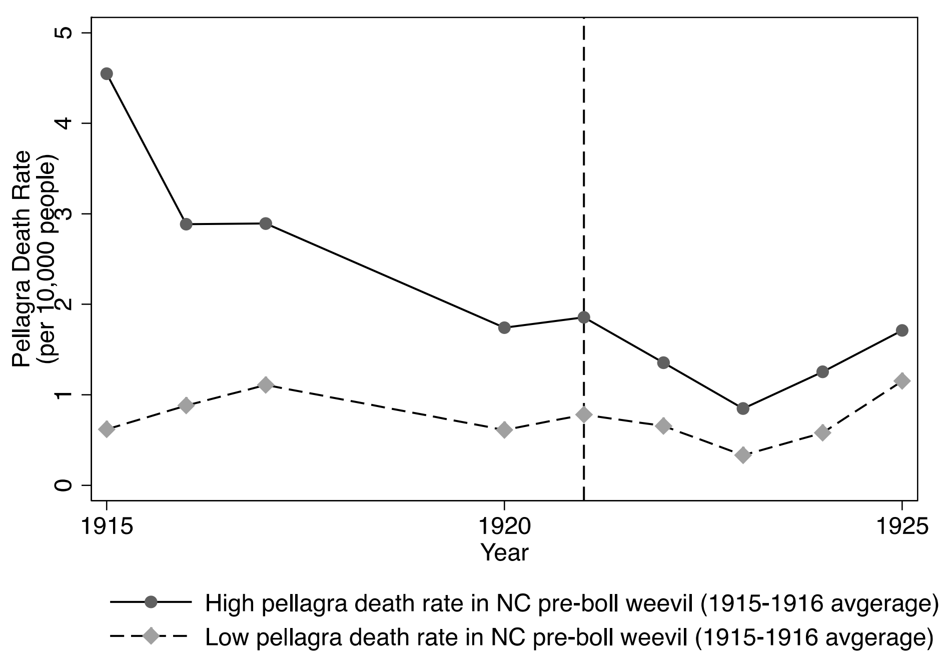


Figure 6: Pellagra and Voluntary Fortification

Notes: This figure displays an event-study of the effect of voluntary fortification on the pellagra death rate. It is generated by estimating equation (3) in the text, but replacing the treatment indicator with a series of indicators that turn on for each year in the five years preceding and following 1938. The indicator for the fifth year before 1938 includes all years 1925-1933 and the indicator for the fifth year after 1938 includes 1943-1949. The coefficients on the indicators are plotted and connected with the blue line. The dashed red lines are the 95% confidence interval.

Table 1: Corn consumption in six South Carolina mill towns

	Shipped cornmeal (percent)	Local cornmeal (percent)
Consumed daily	58%	12%
Consumed habitually	22%	6%
Consumed rarely	10%	2%
Never consumed	10%	80%
Observations	5151	5089

Source: Siler et al. (1914) pg. 21 and pg. 34.

Table 2: Southern Diets 1935 - 1936

	All Southern households	Southern urban households	Southern rural households	Non-Southern households
	(1)	(2)	(3)	(4)
Pounds of cornmeal used in past week	2.81***	1.42***	3.67***	0.07
Pounds of hominy grits used in past week	0.62***	0.68***	0.59***	0.02
Pounds of cornmeal and hominy grits used in past week	3.43***	2.1***	4.25***	0.09
Pounds of white bread used in past week	2.31***	4.21	1.13***	4.33
Observations	1473	564	909	2740

Source: Study of *Study of Consumer Purchases in the United States, 1935-1936.* Consumer Purchases in the United States, 1935-1936 accessed on ICPSR. Significant differences in column means relative to column (4) are reported.

* p<0.1, ** p<0.05, *** p<0.01

Table 3: Relation between crop acreage and pellagra

	log pellagra death rate				
Geographic level:	Counties in NC and SC (1919, 1924, 1929)				
	(1)	(2)	(3)	(4)	(5)
Log cotton acres per capita	0.139				0.188*
	(0.107)				(0.107)
Log corn acres per capita		-0.442*			-0.511**
		(0.228)			(0.234)
Log peanut acres per capita			-0.628***		-0.593***
			(0.203)		(0.192)
Log sweet potato acres per capita				-1.166**	-0.132
				(0.487)	(0.507)
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	309	309	309	309	309
States or counties	103	103	103	103	103

Notes: This table reports OLS estimates from equation (1) in the text. The unit of observation is county-years. Standard errors, reported in parentheses, are clustered at the county-level. See Section 4 of the text for details on the dependent and independent variables. All columns restrict to counties that harvested over 100 acres of cotton in 1889.
* p<0.1, ** p<0.05, *** p<0.01

Table 4: The boll weevil and crops

	Log cotton acres per capita	Log cotton yield	Log corn acres per capita	Log peanut acres per capita	Log sweet potato acres per capita	Log tobacco acres per capita
Geographic level:	Counties in NC and SC (1909, 1919, 1924, 1929)					
	(1)	(2)	(3)	(4)	(5)	(6)
(1): Post boll weevil	0.179***	0.00618	-0.0196	0.0119	0.00350	0.0136
	(0.0225)	(0.0191)	(0.0136)	(0.00962)	(0.00432)	(0.0135)
(2): Post boll weevil * high county pre-boll weevil cotton acres per capita (1909)	-0.160***	-0.0760***	0.0966***	0.0193	0.00851**	-0.0322
	(0.0479)	(0.0241)	(0.0241)	(0.0140)	(0.00331)	(0.0258)
(3): Linear combination: (1) + (2)	0.0188	-0.0698***	0.0770***	0.0312**	0.0120***	-0.0185
	(0.0354)	(0.0174)	(0.0227)	(0.0150)	(0.00414)	(0.0263)
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Quadratic time trend interacted with share of cotton in total acres harvested in 1889	Yes	Yes	Yes	Yes	Yes	Yes
Observations	408	408	408	408	408	408
Counties	102	102	102	102	102	102

Notes: This table reports OLS estimates from equation (2) in the text. The unit of observation is county-years. Standard errors, reported in parentheses, are clustered at the county-level. See Section 4 of the text for details on the dependent and independent variables. All columns restrict to counties that harvested over 100 acres of cotton in 1889. High county pre-boll weevil cotton acres per capita is an indicator variable that takes a value of one for counties that are in the top 25% of the distribution of cotton acres per capita in North Carolina and South Carolina in 1909. * p<0.1, ** p<0.05, *** p<0.01

Table 5: The boll weevil and pellagra

	log pellagra death rate					
Geographic level:	Counties in NC and SC (1915-1925)			Counties in NC and SC (1915-1929)		
	(1)	(2)	(3)	(4)	(5)	(6)
Post boll weevil	-0.267***	-0.253***	-0.193***	-0.236***	-0.236***	-0.201***
	(0.0475)	(0.0483)	(0.0507)	(0.0452)	(0.0462)	(0.0474)
Post boll weevil * county pre-boll weevil pellagra death rate (1915-1916 average)		-0.183***			-0.148***	
		(0.0310)			(0.0272)	
Post boll weevil * high county pre-boll weevil cotton acres per capita (1909)			-0.270***			-0.152**
			(0.0652)			(0.0627)
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1353	1353	1353	1917	1917	1917
Counties	141	141	141	141	141	141

Notes: This table reports OLS estimates from equation (3) in the text. The unit of observation is county-years. Standard errors, reported in parentheses, are clustered at the county-level. See Section 4 of the text for details on the dependent and independent variables. Other controls include: county specific time trends in the malaria death rate and county specific time trends in the percent of the county population living in an urban area. The county pre-boll weevil pellagra death rate is standardized to have a mean of zero and a standard deviation of one. High county pre-boll weevil cotton acres per capita is an indicator variable that takes a value of one for counties that are in the top 25% of the distribution of cotton acres per capita in North Carolina and South Carolina in 1909. * p<0.1, ** p<0.05, *** p<0.01

Table 6: Placebo tests

	log pellagra death rate	log typhoid death rate	log tuberculosis death rate	log measles death rate	log pneumonia death rate
Geographic level:	Counties in NC (1915-1925)				
	(1)	(2)	(3)	(4)	(5)
Post boll weevil	-0.187***	0.0497	0.0323	-0.00504	0.0355
	(0.0611)	(0.0685)	(0.0454)	(0.0563)	(0.0427)
County FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes	Yes
Observations	882	882	882	882	882
Counties	98	98	98	98	98

Notes: This table reports OLS estimates from equation (3) in the text. The unit of observation is county-years. Standard errors, reported in parentheses, are clustered at the county-level. See Section 4 of the text for details on the dependent and independent variables. Other controls include: county specific time trends in the malaria death rate and county specific time trends in the percent of the county population living in an urban area.

* $p<0.1$, ** $p<0.05$, *** $p<0.01$

Table 7: Bread Enrichment Standards proposed by FDA (1941)

	Minimum (mg)	Maximum (mg)
Thiamine	1.1	1.8
Riboflavin	0.7	1.6
Niacin	10	15
Iron	8	12.5
Optional Ingredients:		
Vitamin D	150	750
Calcium	300	800

Source: Food and Bread Enrichment 1949 - 1950; National Research Council Committee on Cereals.

Table 8: Voluntary fortification and pellagra

	log pellagra death rate					
Geographic level:	Counties in NC and SC (1925-1949)			State (1925-1949)		
	(1)	(2)	(3)	(4)	(5)	(6)
Post voluntary fortification * county pre-niacin pellagra death rate (1928)	-0.242***		-0.230***			
	(0.0262)		(0.0270)			
Post voluntary fortification * high county pre-niacin cotton acres per capita (1909)		-0.240***	-0.103***			
		(0.0461)	(0.0372)			
Post voluntary fortification * state pre-niacin pellagra death rate (1928)				-0.0510***		-0.0527***
				-0.0029		-0.00393
Post voluntary fortification * state pre-niacin cotton acres per capita (1909)					-0.0102	0.00568
					-0.0143	-0.00462
State FE	No	No	No	Yes	Yes	Yes
County FE	Yes	Yes	Yes	No	No	No
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3525	3525	3525	292	292	292
States or counties	141	141	141	12	12	12

Table 8 (continued)

Notes: This table reports OLS estimates from equation (3) in the text. The unit of observation in columns (1)-(3) is county-years and the unit of observation in columns (4)-(6) is state-years. Standard errors, reported in parentheses, are clustered at the county-level in columns (1)-(3) and at the state-level in columns (4)-(6). See Section 4 of the text for details on the dependent and independent variables. Other controls include: county (or state) specific time trends in the malaria death rate and county (or state) specific time trends in the percent of the county population living in an urban area. States included in the analysis in columns (4)-(6) are: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, and Virginia. Texas did not report the state level pellagra death rate in 1928 and is, therefore, excluded from the analysis. Continuous intensity variables are standardized to have a mean of zero and a standard deviation of one. High county pre-boll weevil cotton acres per capita is an indicator variable that takes a value of one for counties that are in the top 25% of the distribution of cotton acres per capita in North Carolina in 1909. * $p<0.1$, ** $p<0.05$, *** $p<0.01$

Table 9: Fortification laws and pellagra

	log pellagra death rate							
Geographic level:	Counties in NC and SC (1925-1949)				State (1925-1949)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post fortification law	-0.183***	-0.116***	-0.0489	-0.0373				
	(0.0317)	(0.0318)	(0.0347)	(0.0328)				
Post fortification law * county pre-niacin pellagra death rate (1928)		-0.191***		-0.176***				
		(0.0214)		(0.0163)				
Post fortification law * high county pre-niacin cotton acres per capita (1909)			-0.238***	-0.148***				
			(0.0407)	(0.0289)				
Post fortification law					-0.0279**	0.00552	-0.0271**	0.00725
					(0.0118)	(0.0136)	(0.011)	(0.0113)
Post voluntary fortification * state pre-niacin pellagra death rate (1928)						-0.0286***		-0.0306***
						(0.00595)		(0.0047)
Post voluntary fortification * state pre-niacin cotton acres per capita (1909)							-0.00941	0.00748
							(0.0118)	(0.00803)

Table 9 (continued)

State FE	No	No	No	No	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	No	No	No	No
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3525	3525	3525	3525	292	292	292	292
States or counties	141	141	141	141	12	12	12	12

Notes: This table reports OLS estimates from equation (3) in the text. The unit of observation in columns (1)-(3) is county-years and the unit of observation in columns (4)-(7) is state-years. Standard errors, reported in parentheses, are clustered at the county-level in columns (1)-(3) and at the state-level in columns (4)-(7). See Section 4 of the text for details on the dependent and independent variables. Other controls include: county (or state) specific time trends in the malaria death rate and county (or state) specific time trends in the percent of the county population living in an urban area. States included in the analysis in columns (3)-(5) are: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, and Virginia. Texas did not report the state level pellagra death rate in 1928 and is, therefore, excluded from the analysis. Intensity variables are standardized to have a mean of zero and a standard deviation of one. High county pre-boll weevil cotton acres per capita is an indicator variable that takes a value of one for counties that are in the top 25% of the distribution of cotton acres per capita in North Carolina in 1909. * $p<0.1$, ** $p<0.05$, *** $p<0.01$